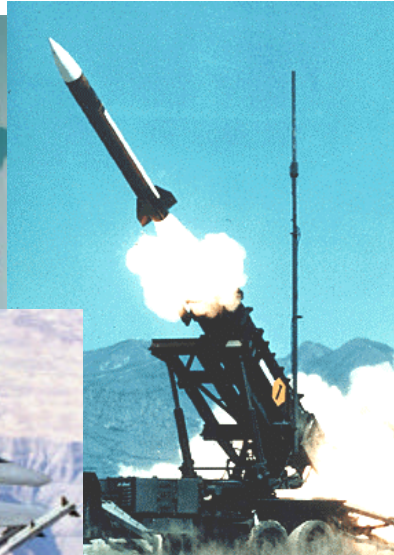
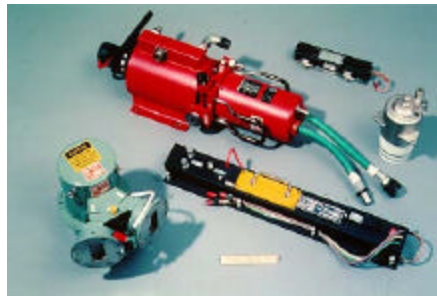




Supply Chain Viability for the North American Microwave Power Tube Industry



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**Supply Chain Viability for
the North American Microwave Power Tube Industry**

September 2002

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13. ABSTRACT <p>The DoD Defense Production (DPA) Act Title III program sponsored this project in response to a critical supply base issue with the objective of strengthening the supplier base to ensure it's future viability. Microwave Power Tubes (MPTs) are of critical concern because of their extensive use in military weapon systems and the limited number of suppliers. The products addressed are helix tape, heater filaments, and cathodes. The project team included IIT Research Institute (IITRI) and four sub-tier suppliers: Semicon Associates, Spectra-Mat, Inc. (SMI), H. Cross Co. and Union City Filament Corp. Boeing Electron Dynamic Devices (EDD), Communication and Power Industries (CPI), and Northrop Grumman Electronic Systems, three of the industry's major MPT producers, served as technical advisors. This task sought to resolve not only general, industry-wide issues, but company specific problems as well.</p> <p>The overall benefits and implications to DoD include: Reduced risk to DoD of production shortfalls; a more responsive supply base, especially for meeting military "surge" requirements; reduced risk of losing the manufacturing process knowledge for these components; lower cost due to simplification of some processes; strategic marketing is enhancing the overall business viability of the four suppliers, especially in recent economic uncertainty; and the adaptation of modern manufacturing engineering tools will position this segment of the supply chain to meet not only the needs of DoD today, but in the future as well. Development of two engineering specifications (EIA-940 and EIA-941) was also a major achievement. Prior to this task, the industry lacked specifications or standards that sufficiently defined performance requirements. A key benefit of standardizing criteria among the MPT producers is cost containment through less material review and scrap. Collectively, this work has resulted in business and manufacturing process improvements that made these companies stronger and advanced the state of manufacturing in the MPT supply chain. As a result of the investment made by DOD, the military supply base for cathodes, helix tape, and heater filaments is a stronger and more viable business base.</p>			
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Executive Summary

Microwave Power Tubes (MPTs) are of critical concern to the Department of Defense (DoD) because of their extensive use in military weapon systems and the limited number of suppliers who can provide the necessary materials and components to produce these high-frequency, high power amplification devices.

Many of the critical suppliers to the MPT industry are small businesses and there is insufficient market incentive for them to invest or improve business practices related to meeting the component needs of MPTs. The consequence is a vulnerable supplier base for the MPT industry that is well documented in several DoD sponsored studies. The DoD Defense Production (DPA) Act Title III program initiated this project in response to this critical supply base issue with the objective of strengthening the supplier base to ensure it's future viability.

The DoD, IIT Research Institute (IITRI), the microwave power tube (MPT) producers and suppliers collaborated to structure a program of work. Selection of the materials and components to be addressed was based on criticality, probability for success within the near-term, and available funding. The products chosen for inclusion in this program were helix tape, heater filaments, and cathodes.

IIT Research Institute (IITRI) led the project team for this program. Four subtier suppliers participated including two cathode manufacturers, Semicon Associates, (a subsidiary of Ceradyne, Inc.) and Spectra-Mat, Inc. (SMI). Semicon Associates is has annual sales of \$8 million and employs 80 people. They are located in Lexington, Kentucky. Spectra-Mat, Inc. (SMI) is located in Watsonville, California; employs about 60 and has annual sales of \$5 million. H. Cross Company of Weehawken, New Jersey is the sole source manufacturer of helix tape. They employ about 50 people, and annual sales are \$5 million. Union City Filament (UCF) Corporation, is the only independent producer of cathode heater filaments. They have annual sales of \$3 to \$4 million, employ 40 people, and are located in Ridgefield, New Jersey.

Boeing Electron Dynamic Devices (EDD), Communication and Power Industries (CPI), and Northrop Grumman Electronic Systems, three of the industry's major MPT producers, served as technical advisors on the project team to verify and validate process and material changes as well as to assist the subtier suppliers in changing business practices.

This DPA Title III program sought to resolve not only general, industry-wide issues, but company specific problems as well. The primary objectives of Semicon Associates and Spectra-Mat were to provide materials and services of escalating complexity, uniformity, reliability, and value to the MPT manufacturing community. The primary objectives of both Union City Filament and H. Cross were to formally qualify alternative sources of raw material in order to mitigate production delays and yield losses that have characterized the existing sole source of supply as well as to mitigate the risk of losing the only source for material supply. Also, each supplier developed it's own set of metrics for evaluating manufacturing improvements and

baselined those factors. This provides not only a mechanism to evaluate the effectiveness of those changes, but also serves as input to their future operational decisions.

Specific process improvement tasks by each of the four subtier suppliers are illustrated in the table below. It is important to recognize that the manufacturing improvements that were achieved will impact the entire supply chain. For example, H. Cross has initiated supplier management program for their vendors. Another is that the acceptance criteria developed by this program has already been accepted by two additional MPT producers, Teledyne Electronic Technologies and Triton Services Inc.

Summary of Manufacturing Process Improvement Projects By Subtier Supplier

Semicon Associates <ul style="list-style-type: none"> • Documentation Update • Method Sheet Development • Cathode Acceptance Criteria • Implementation of Advanced Joining Methods 	Union City Filament <ul style="list-style-type: none"> • Qualification of Alternative Material Supplier • Implementation of Eddy Current Testing • Process Mapping and Computer Simulation of Key Processes
Spectra-Mat, Inc. <ul style="list-style-type: none"> • Surface Analysis • Evaluation of Alternative Sputter Coating Method 	H. Cross Company <ul style="list-style-type: none"> • Qualification of Alternative Material Supplier • Enhanced Non-Destructive Testing • Material Analysis

Each of the four companies made major advancements in their technical capabilities and business practices, as illustrated below.

Semicon Associates has achieved the following:

- A 30% reduction in training time,
- ISO 9001:2000 compliant,
- On-time delivery has been improved by 27%
- Generated a database of more than 900 method sheets, 400 pages of processing documentation, and 900 digital photographs illustrating acceptance criteria,
- Generated \$80,000 in tangible annual savings.

The main objective for Spectra-Mat, Inc. was to generate a data source for future process improvements. Their accomplishments include:

- Current processes were baselined,
- Implemented the cathode acceptance criterion created under this program, and
- Achieved an overall improvement in production documentation, proving readily available records for work orders, incoming materials, and inventory management.

Union City Filament successfully conducted three major manufacturing projects:

- Qualified an alternate material supplier, eliminating their single source dependence;

- Developed a Visio® process map of factory operations and a simulation model using Arena software®; and
- Evaluated and implemented eddy current testing for incoming material. UCF collected and compared baseline data before and after. A total of 35,909 piece parts were inspected. Results show a 57% reduction in overall scrap rate.

The major achievements of H. Cross Company can be summarized as follows:

- Qualification of alternate raw material suppliers,
- Tripled inspection capacity through upgrading and improving eddy current testing,
- Decreased process throughput time of materials,
- Cross trained over 25% of their employees, and continuing to do so, and
- Instituted a certification program for their suppliers.

In addition, each of the four companies has developed a strategic business plan, a marketing plan, developed a website, and conducted a demonstration/briefing of the achievements of their specific program to not only the project team, but many of their key customers as well.

The overall benefits and implications to DoD can be summarized as follows:

- Reduced risk to DoD of production shortfalls;
- A more responsive supply base, especially for meeting military “surge” requirements;
- Reduced risk of losing the manufacturing process knowledge for these components;
- Lower cost due to simplification of some processes;
- Strategic marketing is enhancing the overall business viability of the four suppliers, especially in recent economic uncertainty; and
- The adaptation of modern manufacturing engineering tools will position this segment of the supply chain to meet not only the needs of DoD today, but in the future as well.

A major achievement of this program was development of two engineering specifications that define processing and final acceptance criteria for dispenser cathodes and cathode heaters (filaments). Prior to this program, the MPT industry did not have specifications or standards that sufficiently defined their performance requirements. This program provided the framework, funding, and technical coordination for these two documents. A key benefit of standardizing the criteria among the MPT producers is cost containment of heaters and cathodes through less material review and scrap.

The MPT industry and their respective suppliers are already utilizing these specifications. The Naval Surface Warfare Center (NSWC), Crane Division will maintain the documents and the Electronic Components, Assemblies, and Materials Association (ECA) of the Electronics Industries Alliance will take ownership of the documents. It is anticipated that this initial effort will provide the impetus for the development of additional documents for manufacturing of other MPT components and processes.

Collectively, the work of this project team has resulted in business and manufacturing process improvements that have made these businesses stronger and advanced the state of manufacturing in the MPT supply chain. As a result of the investment made by the DOD Defense Production Act Title III program, the military supply base for cathodes, helix tape, and heater filaments is a stronger and viable business base.

1.0 BACKGROUND

Microwave Power Tubes (MPTs) are of critical concern to the Department of Defense (DoD) because of their extensive use in military weapon systems and the limited number of suppliers who can provide the necessary materials and components to produce these high-frequency, high power amplification devices.

MPTs are complex electronic components that emit a high-energy beam millions of times more powerful than the energy in a typical household appliance. They are the enabling technology in high-power electronic systems, especially satellites and radar. MPTs are currently installed in over 150 active DoD Systems throughout the tri-services. It is forecasted that an estimated 80 percent of these will be in service in the year 2010 and that the DoD will require at least 20,000 to 30,000 microwave tubes per year through the year 2025. Notwithstanding these projections, declining defense spending over recent years has reduced industry sales by more than 50 percent. The impact of this reduced spending has been a consolidation of MPT producers and a reduction in the number of companies with the capability to supply the highly specialized materials and components required to make MPTs.

In order to meet the technical performance requirements of MPTs used in military systems, the critical components must be made using specialized and high purity starting material and highly controlled and complex manufacturing processes. The subtier suppliers of these critical components have various technical issues, such as quality, yield, and on-time deliverables that adversely impact their business viability. There is insufficient market incentive for these small business suppliers to invest or improve business practices related to meeting the product needs of the MPT industry. The consequence is a vulnerable supplier base for the MPT industry that is well documented in several DoD sponsored studies.

In 1996, the U.S. Department of Defense, Joint Defense Manufacturing Technology Panel, Electronics Processing and Fabrication Sub-panel, requested MTIAC to conduct a study of the status of the use of Flexible Manufacturing in the Production of Microwave Power Tubes (MPT). The results of the study indicated that one major weakness in the industry is the reliance of MPT manufacturers on a very limited number of subtier suppliers for several components and materials. At least 20 components or materials have only one or two suppliers globally. Furthermore, many of these suppliers were facing the same dramatic declines in sales due to reduced Defense spending but as a consequence of under-capitalization, have insufficient technical and financial resources to adequately address these challenges.

The DoD Defense Production Act Title III program represented one mechanism, but perhaps the most appropriate approach, to addressing the supply base issue.

2.0 OBJECTIVES AND SCOPE

The guiding objectives of the DoD Defense Production Act (DPA) Title III program are to establish assured, affordable, high quality production capacity through business development activities, metrics, cost reductions, yield improvements, process improvements, and customer partnerships to evaluate and use initial products. Business partnership is considered to be the key to successful transition of a DPA Title III program. Accordingly, the overall objective of this project was to enhance the long-term viability of the domestic MPT subtier supplier base.

The underlying goal of this program was to ensure that DoD has a long-term source of the MPT components produced by the four subtier supplier companies and incorporated by the three manufacturers for use in military systems. The scope of this program addressed data resources in the U.S. and U.S. manufacturers.

This program was conducted as a Technical Area Task under the DoD Manufacturing Technology Information Analysis Center (MTIAC). The project team for this program included IIT Research Institute (IITRI), Boeing Electron Dynamic Devices (EDD), Communication and Power Industries (CPI), Northrop Grumman Electronic Systems, H. Cross Company, Semicon Associates, (a subsidiary of Ceradyne, Inc.), Spectra-Mat, Inc. (SMI), and Union City Filament (UCF) Corporation.

The Manufacturing Technology Information Analysis Center (MTIAC) is operated by IITRI, for the Defense Technical Information Center (DTIC) and the Defense Supply Center Columbus. Sponsorship for this program was provided by the Defense Production Act, Title III, U.S. Air Force, Wright-Patterson Air Force Base 45433-7801. This project conformed to the objectives of Section 303, Title III of the Defense Production Act (DPA) of 1950 (as amended 50 U.S.C. app. 2093) which authorizes the use of Government funds to encourage industry to establish or expand production capacity needed for national security.

3.0 APPROACH

MTIAC, the microwave power tube (MPT) producers, their suppliers, and DoD worked collaboratively to structure the project plan and program of work. Selection of the materials and components to be addressed were based on criticality, probability for success within the near-term, and available funding. The products chosen for inclusion in this program are helix tape, heater filaments, and cathodes.

MTIAC worked with the Defense Production Act Title III office to structure the program concept and project team. The approach was to initially conduct a project definition meeting, which was held on 11 October 2000 in San Francisco. This meeting provided a written explanation of DoDs expectations and served to clarify questions and issues. Breakout sessions were also conducted to facilitate individual questions that may have included industrially competitive issues. Breakout sessions were also held on 12 October to allow industry partners a venue to jointly form their technical work plans and establish their specific project teams.

In accordance with the DoD statement-of-work, each of the companies developed strategic business and marketing plans, baselined key and measurable manufacturing process capabilities to provide a metric for comparison, and conducted a capability demonstration. MTIAC managed the program, maintained awareness, responded to technical direction from the DoD user community, and conducted portions of the technical effort. In summary, MTIAC worked directly with the key suppliers of MPT components and materials, key MPT manufacturers, and DoD to create an improved and more viable supply base for critical products, components, and enabling materials.

Understanding the requirements for process and material change and to ensure that changes made by the subtier suppliers would be accepted by their customers, Boeing EDD, Northrop Grumman Electronic Systems, and CPI acted in an advisory role to IITRI and the subtier suppliers. These three MPT manufacturing companies represent over 85 percent of the North American production of MPTs. It was recognized that process or material changes made by subtier suppliers could not negatively impact the integrity of the component or the performance of the final product. It was further recognized that enhancing the viability of each subtier supplier would ensure a stable and available source of supply of MPT industry-specific, critical components. To that end, Boeing EDD, Northrop Grumman Electronic Systems, and CPI served as technical advisors to verify and validate process and material changes, and worked with MTIAC and the subtier suppliers to improve business practices. In addition, they helped suppliers in developing alternative technical approaches and in defining the requirements for verification and acceptance of the critical product at the completion of each process step. Improved processes are reducing the occurrence of manufacturing problems and product rejects that, in turn, reduced the cost and technical resources currently expended by both suppliers and the MPT manufacturers.

4. INDUSTRY ISSUES

Under the DPA Title III, the program was able to address general issues that were prevalent among all of the project participants as well as those problems and challenges that were specific to H. Cross, Semicon, Spectra-Mat, and Union City Filament.

General, industry-wide issues and factors that were considered in conducting this program and that impact the MPT industry overall are as follows:

- Limited understanding and documentation of the capabilities and resources within the supply base
- Lack of a uniform policy and procedure by the MPT producers in dealing with suppliers
- Limited number of independent suppliers for key materials
- Declining and dramatically fluctuating market
- Consolidation and acquisitions within the microwave power tube producing industry
- Limited utilization of emerging manufacturing and material technology
- Industry specific standards and specifications,
- Documentation on products and processes
- Quality of incoming raw materials or pre-assembled parts
- Cross training and improvement of worker skills

All of these issues are interrelated and are very critical in providing the best possible product with the shortest lead-time. A main concern for the smaller subtiers is their dependency on a particular individual that possesses the most knowledge of a process or procedure. With properly documented processes and/or specifications coupled with cross training of employees they can reduce their dependency on individuals and become more autonomous. Furthermore, the creation of specifications allows companies to refer to a common document and have similar terms, creating a minimum requirement to the quality produced by each individual company.

4.1 Company Specific Issues

Each of the subtier suppliers developed a strategic business plan and marketing plan, but approached it uniquely to their own businesses. Some companies brought to the program an in-depth knowledge of their market and competitive environment, while others sought outside assistance.

The primary objectives of Semicon Associates and Spectra-Mat were to provide materials and services of escalating complexity, uniformity, reliability, and value to the MPT

manufacturing community. The primary objectives of both Union City Filament and H. Cross were to formally qualify alternative sources of raw material in order to mitigate production delays and yield losses that have characterized the existing sole source of supply. Taken together, the work of this team resulted in business and manufacturing process improvements that have made these businesses stronger and enhanced the supply chain viability of the MPT industry.

4.2 Specifications and Standards – Industry Issues

A major problem identified in the development of this program was the lack of understanding between the Microwave Power Tube producers and the independent cathode suppliers as to why a component is accepted or rejected. Cathodes and heater filaments were being produced based on drawings and part specifications, but the criteria used to determine what was an acceptable part was not clearly defined and there were no written standards or guidelines established. Further, it was recognized that standardizing the criteria among the MPT producers, would help to contain costs for the cathode and heater filament suppliers, as well as the MPT producers themselves.

For the most part, MPTs are produced by divisions or groups within very large companies that are affiliated with numerous trade associations. However, the primary organization for representation of microwave power tubes (or vacuum electronic devices) is the Electronic Components, Assemblies, and Materials Association (ECA) of the Electronics Industries Alliance.

Prior to this program, the MPT industry did not have standards and specifications that were specific to their industry segment. The approach used in this program was to form two working groups, one for Cathodes and the other for Tungsten products, especially helix wire and heater filaments. The primary goals set by the working groups were development of an engineering specification for dispenser cathodes and development of an engineering specification for cathode heaters (filaments). In addition, the working group forum provided an opportunity for information exchange between the participants, as well as consideration of new technology and related issues.

The two Working Groups were formed in May 2001 and the final documents were completed in April 2002. Industry leadership for the Cathode Working Group was provided by CPI. Northrop Grumman Electronic Systems provided a chairperson for the Tungsten Products effort. IITRI provided administrative and engineering support. Other members of the Working Groups included representatives from Boeing EDD, Semicon Associates, Spectra-Mat Inc., Union City Filament, and H. Cross Company. Although, not a contractual participant, Teledyne Electronics also attended and contributed to some of the meetings. Both Teledyne Electronics and Triton were asked to review the final documents and concur with and accept them.

A series of five working group meetings were held throughout the year. After each meeting, the latest version of the document was distributed to the team, changes incorporated, and issues for resolution were set for the next meeting. The final products

were the result of six revisions. Another product of the Working Group efforts is the Process Audit Form, which is incorporated in the dispenser cathode document.

The next steps are dissemination, implementation, and maintenance of these documents. Naval Surface Weapons Center (NSWC), Crane Division has offered to maintain the documents. Mr. Joe Dutkowski of NSWC, Crane participated in the development process and provided guidance to the Working Group team regarding DoD Documentation Control and Information Security Procedures, Document Number 1255-8843-940019. Copies of this document were provided to the team in an electronic format.

The plan is for the ECA to take ownership of the documents. Included in the documents are a recommendation and approach for implementation and periodic revision of the two specifications. Further, it is anticipated that this initial effort will provide the impetus for the development of additional documents for manufacturing of other MPT components and processes. The following section provides a more in-depth discussion of the technical development and implications.

4.3 Dispenser Cathode and Cathode Heater Engineering Specifications

Problems common to both the suppliers and the microwave power tube producers are detection of defects and acceptance criteria. Defects are frequently not detected until the product is part of a higher-level assembly. Product returns, schedule delays, and the cost of rework or remanufacture are a tremendous burden on the subtier, small business suppliers. It was determined that what was needed was a well-defined process and end item criteria along with control metrics.

Development of the specifications was an iterative process. A series of working group meetings were held, as well as interim telecons, each addressing the next revision. At the initial meeting, cathode related problems were discussed with an emphasis on Inspection Criteria and Process Controls required to screen for product defects and monitor process trends. This laid the groundwork for issues to be addressed in this “acceptance criteria”. It was decided that common acceptance criteria would utilize representative photographs to the degree practical, and that measuring instrumentation and methods would be standardized for those variables with quantitative limits. In order to accommodate the individual differences among the MPT producers it was important to achieve mutual agreement on common acceptance criteria, referred to as Level 1 and company-level specification, which was referred to as a higher level standard, Level 2. Another goal set forth by the group was to establish process control requirements and associated process audit criteria.

In meetings at Spectra-Mat and Semicon, the working group initiated and refined a step-by-step process map including key characteristics. It was determined that the fundamental processes for cathode manufacture were nearly identical between the two suppliers and therefore a single, generic process audit format could be developed. In addition to identifying key process characteristics, several categories of interest were recognized as being critical to effective process control. These are the following:

- Critical process equipment subject to preventative maintenance requirements,
- Critical measurement instruments subject to calibration requirements,
- Critical raw materials purchased to internal specifications, and
- Critical materials subject to formal test and qualification.

Areas of emphasis were common methodology for:

- Measuring cathode-operating temperature,
- Measuring heater resistance,
- Measuring impregnate weight gain,
- Defining and verifying pore size and distribution,
- Define weld quality standards, and
- Process audit and control.

The goal for the group was to develop common measurement methods that could best accommodate each company's specific equipment. Temperature measurement is a key technical issue in producing cathodes. CPI provided a "shop-floor" opportunity for the working group to address this problem as well as arranging for the group, and invited guests, to hear a presentation from equipment vendor Land Instruments on non-contact temperature measurement. The representative from Land discussed disappearing filament pyrometry (DFP), blackbody emitters, emissivity, reflectivity, sensitivity and subjectivity of human eyesight, monochromatic radiation thermometers, black body cavities (use in calibration), published emissivity values and their uses (DeWitt/Nutter), and other topics.

At the meeting, it was established that it would be possible to produce a table of emissivity values for cathodes. It was clarified that values typically reported by the Cathode Working group members are brightness, not true temperature. It was agreed that following ITS-90 (International Temperature Scale 1990) is the best way to calibrate a radiation thermometer. It was generally agreed that most producers need to upgrade their current equipment in this area.

In conjunction with development of the cathode engineering specification, a process audit form was developed. The goal in the iterative audit form development process was to get feedback from the subtiers regarding the extent/quality/usefulness of the document while disregarding company-specific or proprietary details. Training was raised as a serious issue. It is important that companies certify that they have skilled laborers and that they have the ability to "make" skilled laborers in the future.

A schedule of audits was established. Issues were raised about the appropriate balance between a level of customer surveillance that will provide a confidence level to support

value-added outsourcing and process improvement, and the resulting intrusion and time and cost impact on the supplier. Some options considered include the following:

- Teach each other how to audit, so that they can rely on each other's interpretation.
- The whole process must be based on a fundamental premise of mutual respect,
- They must build toward a supplier self-audit process, and
- Motivation must be internal, not external.

It was recognized that above and beyond proper equipment operation, conforming material and sound processes, there is a great deal of manual assembly that relies on the individual process controls of the operator. The audit process serves to verify that the operator has been effectively trained and demonstrates the skills to perform said process.

Process audits of both Semicon and SMI were conducted by the engineering personnel from Boeing EDD, CPI, and Northrop Grumman. The form used in conducting these process audits was developed by the Cathode Working Group. These audits served as a guide for improvement of the audit form itself, as well as process issues. The end result was a mutually accepted format that has been incorporated into the Engineering Specification for Dispenser Cathodes. In addition, CPI has shared their approach and audit form with Navy customers for other parts and applications and will be implementing the process audit form and methodology to other parts beyond those addressed in this study.

4.4 Product Evaluation and Acceptance of Alternate Material Supplier for Helix Tape and Wire

One of the major supplier risks identified in the development of this program was the sole source dependency for high purity Tungsten and Tungsten-Rhenium starting material for manufacturing heater filaments and helix tape. The previously single qualified supplier, Sylvania, was purchased by an offshore firm and much of the “processing know-how” was lost to retirement. The lighting industry represents the major business segment for Osram Sylvania and the high quality specialty material used for MPT components is an extremely small portion of their overall production. Hence, orders for these materials were lower priority, lead-times for starting material became a significant problem, and the cost for a minimum order increased dramatically. H. Cross and Union City found it necessary to carry large inventories.

It was general knowledge that there were other potential suppliers of Tungsten and Tungsten-Rhenium wire, but they had not been qualified for use in MPT helix tape or heater filaments. Also, there was another major variable to consider which is that the chemical composition of the material offered by alternate suppliers is slightly different from the then current source. Although the material is offered by the same suppliers, H. Cross and Union City Filament had different qualification needs and each uses different

sizes. The three participating MPT producers played a major role in qualification of an alternate material supplier including development of an experimental plan, testing, evaluation, and feedback. Although the material is essentially the same, each of the MPT producers sought some information specific to their needs and that is considered competitively sensitive to the manufacturing operations.

CPI does not use Tungsten-Rhenium for internal production and tested only Tungsten from the alternative sources. Boeing EDD chose to test only Tungsten, but Northrop Grumman Electronic Systems tested both materials. H. Cross researched potential material purveyors and found two new possible sources of Tungsten and Tungsten-Rhenium. The material was acquired, samples made, and tests done to prove that the new material met current specifications and requirements prior to use by industry.

These tests and validations were conducted throughout the entire production process starting with the manufacturing of the heater filaments and helix tape, all the way to the final testing and acceptance of a completed dispenser cathode by the MPT producers. H. Cross Company began verifying the new material for helix tape by sending samples to the MPT producers for chemical and mechanical analysis. These tests determined properties such as spring-back, the material's tendency to return to its original shape after being formed; brittleness; grain structure; size; and purity.

While tests at the primes were continuing, H. Cross conducted their own tests to ensure the new material met their internal quality requirements. After passing the initial tests, the MPT producers supplied specifications to H. Cross for production of the helix tape to be evaluated by them. The following illustrates the sample tape sent to each of the primes.

CPI

Size	Material Type	Company
0.007 inch x 0.015 inch	Tungsten	Nippon
0.007 inch x 0.015 inch	Tungsten	Tokyo Tungsten (AX Grade)
0.007 inch x 0.015 inch	Tungsten	Tokyo Tungsten (EX Grade)
0.012 inch x 0.025 inch	Tungsten	Nippon
0.012 inch x 0.025 inch	Tungsten	Tokyo Tungsten (AX Grade)
0.012 inch x 0.025 inch	Tungsten	Tokyo Tungsten (EX Grade)
0.012 inch x 0.043 inch	Tungsten	Nippon
0.012 inch x 0.043 inch	Tungsten	Tokyo Tungsten (AX Grade)
0.012 inch x 0.043 inch	Tungsten	Tokyo Tungsten (EX Grade)

Northrop Grumman Electronic Systems

Size	Material Type	Company
0.007 inch x 0.015inch	Tungsten	Nippon
0.007 inch x 0.015 inch	Tungsten	Tokyo Tungsten (AX Grade)
0.007 inch x 0.015 inch	Tungsten	Tokyo Tungsten (EX Grade)
0.005 inch x 0.012 inch	Tungsten-Rhenium	Nippon
0.008 inch x 0.025 inch	Tungsten-Rhenium	Nippon
0.012 inch x 0.030 inch	Tungsten-Rhenium	Nippon

Boeing Electron Dynamic Devices

Size	Material Type	Company
0.015 inch x 0.045 inch	Tungsten	Nippon
0.015 inch x 0.045 inch	Tungsten	Tokyo Tungsten (AX Grade)
0.015 inch x 0.045 inch	Tungsten	Tokyo Tungsten (EX Grade)
0.006 inch x 0.011 inch	Tungsten	Nippon
0.006 inch x 0.011 inch	Tungsten	Tokyo Tungsten (AX Grade)
0.006 inch x 0.011 inch	Tungsten	Tokyo Tungsten (EX Grade)
0.004 inch x 0.008 inch	Tungsten	Nippon
0.004 inch x 0.008 inch	Tungsten	Tokyo Tungsten (AX Grade)
0.004 inch x 0.008 inch	Tungsten	Tokyo Tungsten (EX Grade)

After receiving the helix tape samples from H. Cross, Boeing EDD, Northrop Grumman Electronic Systems, and CPI devised a series of tests to determine the validity of the new material. Microscopic optical inspection was performed to examine the surface of the wire for cracks and splits and general surface finish, before rolling it into helix tape. Then they look at the grain structure of the pre-processed helix wire. Grain structure was assessed to determine any processing problems that as a result of mixing the materials or work hardening. Tensile testing determines the flexibility and strength of the wire and

serves as an indicator of the potential final tensile strength of the helix tape.

After the wire was evaluated and accepted, H. Cross then manufactured the wire into helix tape. This tape is then inspected in the same manner as the wire. Since not all materials react to bending the same, the new material is wound into helices using “standard” mandrels and evaluated for “spring-back”. After the spring-back characteristics of the new material is determined, new mandrels are made so that the finished helices will meet engineering specifications.

The process flow for the production of helices from helix tape is as follows.

- Wind tape into helices
- Assess grain structure
- Final check of all processed to date
- Helices are etched
- Heat treatment for stress relief
- Final polishing
- Final Surface inspection
- Analysis of grain structure
- Test for electrical properties
- Install into cathodes

After winding the tape, and the helices are produced grain structure is assessed grain structure to see what affect the winding process had. Final checks of all the processing until now are evaluated and checked for repeatability. The helices are cleaned, etched and heat-treated for stress relief. The helices are final polished and inspected. Again, a cross section is taken and the grain structure is analyzed to see if the material has held up under the manufacturing process.

The finished helices are then installed into a testing fixture and tested for their electrical properties, and the next step is to install them into production cathodes. These cathodes are the same as what would be delivered as final products to customers. They are then installed into test fixtures and turned on to evaluate life and quality of product. Finally, all data is collected and evaluated to determine if the new helix material is acceptable.

After receiving all the data from the MPT producers and coupled with their collaboration with H. Cross, the group had a better understanding of the new materials. For the Allied Material Grade Ax and Ex it was found that the surface finish was approximately 25% better than the currently used material regarding die lines, pitting and gouges. Split-levels were found to be good or better than the currently qualified material based on samples that were provided.

The material showed exceptional formability with very good dimensional control possible. The workability was also found to be much better. It did not cause roll wear as quickly as similar Osram Sylvania material. This was thought possible due to higher purity of the material, 99.99% vs. 99.95%. The Nippon B001 grade surface finish was

very similar to Allied Material with further improvement in lower wire diameters of 0.015 inch and lower. Other properties also showed similarities to the Allied Material Ax and Ex type. The Nippon BR01 3% Tungsten Rhenium had a surface finish that was approximately 30% better than the currently qualified material overall. Splits and formability were good, yet workability was very similar to the Osram material. With the exception of the Ax Grade, Allied Material Tungsten, all samples would be suitable alternatives to the current supplier for the production of helix tape.

5.0 Manufacturing Process Improvements

5.1 Overview

In conducting process improvements, each of the four subtier suppliers developed its own set of metrics for evaluating manufacturing improvements and baselined those factors. This served not only as a mechanism to evaluate the effectiveness of those changes, but also served as input to their future operational decisions. Specifically, the purpose of this program was to identify, assess, and implement manufacturing process improvements that contributed to program objectives, to make processes more flexible to future needs, to enhance reproducibility, to reduce dependence on critical or endangered raw materials, and to reduce current cost or alleviate future cost increases.

MTIAC investigated and searched for optimization of processes to reduce cost and lead-time and worked successfully with each of the proposed critical suppliers in establishing or enhancing quality assurance. Production operations were analyzed for costs and several cost reduction opportunities were targeted and achieved.

Specific process improvement tasks by each of the four subtier suppliers are illustrated in the table below. The roles of each participant and specific technical efforts are provided in the following pages. It is important to recognize that the manufacturing improvements that were achieved will impact the entire supply chain. For example, improved delivery and quality of the products produced by Union City directly improved the lead-time and production operations of the cathode manufacturers.

Summary of Manufacturing Process Improvement Projects and Achievements

Semicon Associates	Spectra-Mat, Inc.	H. Cross Company	Union City Filament
Documentation Update	Surface Analysis	Qualification of Alternative Material Supplier	Qualification of Alternative Material Supplier
Method Sheet Development	Evaluation of Alternative Sputter Coating Method	Enhanced Non-Destructive Testing	Implementation of Eddy Current Testing for Incoming Inspection
Cathode Acceptance Criteria		Material Analysis	Process Mapping and Computer Simulation of Key Processes
Joining Methods			

5.2 Specific Accomplishments

5.2.1 Semicon Associates - Manufacturing Process Improvements

Semicon Associates is a subsidiary of Ceradyne, Inc. Semicon is primarily a cathode producer, with an estimated 75 percent market share, but they also make rare earth magnets. They are located in Lexington, Kentucky; employ approximately 80 people; and have annual sales estimated at \$8 million per year.

The factors chosen by Semicon to baseline are central to the viability of their current business and anticipated growth. The following are measures that Semicon felt would be good for baselining to determine their success from participating in the DPA Title III program with the goal of generating 6 charts per month.

- Internal quality as % of sales (cathodes)
- Customer returns as % of sales-Semicon data (cathodes)
- Customer returns as % of sales-Customer data (cathodes)
- On-Time delivery-Semicon data (cathodes)
- On-Time delivery-Customer data (cathodes)

Specific projects undertaken by Semicon in order to improve their overall process were: documentation update, method sheet development, acceptance criteria (dispenser cathodes and heater filaments), joining methods, and employee training. In addition to this Semicon produced a company brochure as well as a web site (www.semiconassociates.com) to increase exposure and establish new markets.

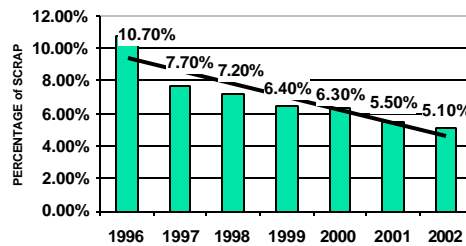
In order to grow and strengthen its business, Semicon Associates has demonstrated forward integration and is capable of providing a more complete assembly. This will present greater revenue and margin and provide the customer with a more complete part with reduced quality risk. Semicon Associates has already successfully built value-added assemblies and the microwave tube industry has gained initial confidence in its abilities. Current in-house expertise and equipment improvement has given Semicon the ability to build cathodes into the gun structure, in keeping with the original overall goal and strategy.

Semicon Associates also played a key role in the development of the engineering specifications that were generated in this program. They provided a large percentage of the photographs and illustrations that are currently in the specifications. They also contributed 2 of the 5 addendums that are attached to the dispenser cathode acceptance criteria and are currently maintaining a large library of photographs and illustrations for future use in the acceptance criteria.

Semicon Associates feels that confidence in their ability to provide products and services to the MPT industry has greatly increased due to its improvement in its documentation system including specifications, procedures, generic work instructions, method sheets, and acceptance criteria. Baseline for the method sheets: 900 pages and they are continuing the activity. They have developed 500 pages of documentation sheets, almost

100 different procedures and the process of updating documentation is also ongoing. Through this progression Semicon has encouraged all of its employees to participate. Getting feedback from the individuals that perform the actual procedures was vital to ensuring that the documentation was clear, concise, and useful.

Direct benefits to Semicon Associates and DoD are seen in 30% reduction of training time, quality and acceptance of product is over 90% and continually improving, and on-time delivery is currently at 85% or better. Cycle time has also improved substantially and is continuing to do so. As a result Semicon has created excitement amongst the workers and a sense of a team atmosphere has been established.



Teams were formed in the plant to supervise particular aspects of the operations and monitor its progress. Results are posted on a weekly basis and provide positive feedback for the employees. The graph above shows percentage of scrap and how it has decreased, especially since participating in program. Scrap dollars as a percentage of sales are on the decline. In furthering its commitment to becoming a more efficient and productive company Semicon has become ISO 9001:2000 compliant, updating all documents to ISO 9001:2000 requirements. This has provided the following benefits: Process controls have resulted in improved product quality (yields); improvements in documentation have resulted in more efficient and effective training. Furthermore, new manufacturing jobs now go to the floor with method sheets complete. These method sheets have positively impacted product quality and training efficiency.

In addition, advanced joining methods for value-added assemblies have been successfully incorporated through the purchase of new equipment and the training of personnel. Optimization matrices are consistent and therefore validate its new joining process. Semicon has developed a matrix of weld settings that provide a good starting point for the target setting. In order to compensate for the variables inherent in the process and product mix, Semicon Associates has begun placing welder settings and acceptance criteria onto their method sheets. The method sheet approach has: reduced set-up times, provided less run-to-run variation, and has reduced training time.

Participating in this program has enabled Semicon to greatly improve its overall manufacturing through improved documentation. For the project-identified processes (4 of the 14 defined project areas) where acceptance is a function of process or equipment,

Semicon developed 34 procedures to control manufacturing and was established as the basis for some of the processes discussed in the acceptance criteria. Through the continual documentation and specification process Semicon has become more autonomous. Semicon has created a larger degree of employee empowerment through cross training and allowing them to participate in creating the documentation for the processes they perform daily. Furthermore process engineering technical resources have been freed from making quality calls to improving processes (prevention). Other benefits from this program include training efficiency through the use of the acceptance criteria.

Product quality has been improved by source recognition. Passing on non-conforming product to the next processing step has been significantly reduced. Cycle times were also reduced and acceptance of product is on the rise. This will provide greater confidence to the primes and perhaps enable Semicon to take on value-added process and allow them to grow for the future.

5.2.2 Spectra-Mat, Inc. - Manufacturing Process Improvements

Spectra-Mat, Inc. (SMI) is a major supplier of cathodes to the MPT industry. They are located in Watsonville, California; employ about 60 people and have annual sales of approximately \$5 million, two fifths associated with the MPT industry. SMI is a long-time supplier of thermionic dispenser cathodes, high vacuum heater packages, filaments, ionizers, ion sources, specialty refractory materials, and microelectronics thermal management materials.

The objective of this project was to test the hypothesis that the new coating technology performed as well or better than their existing coating technology and that there was no negative impact on the integrity of the final product. The main objective for Spectra-Mat, Inc. was to generate a data source for future process improvements to provide SMI direction for continuous improvement and the ability to produce a more predictable dispenser cathode. The experimental approach taken by Spectra-Mat can be summarized as follows:

1. Baseline parts with no coating
2. Baseline parts with coating using their current technology
3. Assess parts made with new coating technology

Not all cathodes are coated. However, if they are, coating is the last step in the cathode manufacturing process. Final surface preparation occurs just prior to coating. SMI has numerous techniques it uses for final surface preparation, and since the final processing steps influence the surface conditions and theoretically effect quality and quantity of emissions it is important to understand these processes. Basically, there are three types of final surface preparation. These are: EDTA which is a chemical etching; final machining, usually using a lathe; and a process called "back etching" which is done in the sputter chamber.

For this project, SMI baselined cathodes prepared with the different processing methods in general use in their manufacturing facility, to determine the impact they have on cathode performance. The baseline data will enable SMI to improve its process. Currently there exist tests with 100,000+ hours life notwithstanding. Below is a list of the cathodes that were used for Baseline. In all, four cathodes (SN1-SN4) were mounted in a diode structure. Tests were carried out at the FDE Company's facilities in Beaverton Oregon.

- Two units were "B" type cathodes (5:3:2-80 cathode)
- Two units were "M" type cathodes (5:3:2-80+ cathode)

Spectra-Mat measured general performance criteria from the diode tests for a period of 336 hours after the initial test. In order to provide information about the baseline diode cathodes, high magnification photos of the cathode surface were taken and an ESCA analysis was done to review the initial state of the cathode surface. Specific elements on the cathode that were examined included porous structure/pore count, surface roughness, the general pattern from machining, and elemental analysis of the constituents. Afterwards a total of sixteen cathodes and diodes (SN5-SN20) were built over the following weeks with specific process steps to be followed. The samples were then compared to the baseline data. From this, SMI could determine to what extent the various processing techniques affect cathode performance and quantify the results if possible. Finally, it could also describe what techniques can be applied to various cathodes. For the 2 M-type cathodes, test coupons were coated. The existing sputter coating was measured in thickness and uniformity and a set of tests runs were done to determine tension or compression of the coating. A check on the composition of the coating was performed as well.

Data confirms that all of the current processes work well. Variation may exist, but is close to noise levels. From the tests it was determined that SMI can final machine every cathode, etch every cathode, EDTA clean almost all cathodes, and "high polish" only a limited amount of cathodes. No conclusive evidence could support one process over the other that was tested but a few comments can be made. From the test results the preferred process seems to be to process without final machine, with "high polish" and with EDTA cleaning. Overall it can be said that each process can provide a good cathode. However in order to meet the dimensional tolerances presented by the MPT producers of traveling wave tubes, eliminating final machine is not an option. Also an important note should be made that these tests were carried out for 0.134 inch cathodes, and that results may not scale well to other size cathodes.

Another project for SMI under this program was to evaluate "sputtering technology" through a new sputter coating machine that may replace the current machine they use for their "M" coated cathodes. Using completed B-type cathodes and Spectra-Mat's existing coating system, they baselined the existing sputter system; using scanning electron microscope (SEM) photos to characterize the porosity of the cathodes prior to M-coating. Using high-resolution methods to characterize the surface state after M-coating and sintering. They also baselined the coating's stress via molybdenum foil test coupons and developed a method for driving out the coating stresses.

SMI currently has the new system operating and has run samples. SMI has confidence in their ability to run 4000-angstrom thick coatings. Although to date they do not fully understand the implications of the coating. SMI believes they have the correct thickness but seems to be much stronger. SMI produced nine traveling wave tube cathodes, 0.142 for testing. CPI provided facilities for performing the necessary tests on the sputter coated cathodes.

A process for the new sputter coating system was developed. Thickness values are comparable to old system as well as its constituents. Knee points consistent with old process. Work functions are consistent and lower than the old process. SMI needs better life from target. They also need to understand area coverage. Currently SMI is exploring various operating parameters to get the system tuned to meet the cathode communities' needs. SMI's goal under this program is to insure they get working parts and a working machine, and they have mentioned that they will spend the better part of a year fine-tuning the specifics. Improved operating procedures for both systems in place.

Under this program, SMI was able to baseline all of its current processes and now has a better understanding of them, and can use this information for future comparison. Produced objective data to guide improvement initiatives. Improved overall understanding of surface conditions and coating processes. M-Coat process somewhat understood, new technology "M"-coating evaluated, with continuing development. Additional benefits gained from participating in this DPA Title III program are and overall improvement in production by having documentation following work orders and incoming materials and inventory have readily available records. SMI employees are also now using the cathode acceptance criterion that was created under this program.

5.2.3 Union City Filament - Manufacturing Process Improvements

Union City Filament, the only active independent producer of the Tungsten and Tungsten alloy wire heater filaments essential to microwave power tubes, is located in Ridgefield, New Jersey. They employ approximately 40 people, have annual sales under \$5 million, and have been supplying heater filaments to the MPT industry for over 50 years.

UCF identified three manufacturing projects short-term projects to be conducted within their program with the goal of increasing their viability in the supply chain. These projects were: qualification of an alternate material supplier, evaluation and implementation of eddy current testing of incoming raw material, and development of a process map of factory operations and a simulation model of key operations.

5.2.3.1 Qualification of Alternate Material Suppliers

Because the current 3% Rhenium-Tungsten wire required to make the filament heaters was only available from a single qualified supplier (Osram-Sylvania), it was essential to qualify an alternative source to minimize the potential disruption to the supply chain

caused by lack of raw material or drop in quality. For this alternate source Metal Cutting, the master distributor in the U.S. for Nippon Tungsten of Japan was used.

Filament heaters of different sizes and materials were designed, produced, and tested at the cathode manufacturers (Semicon, Spectra-Mat) for acceptability. Union City Filament was responsible for obtaining the Tungsten Rhenium wires, establishing the specifications, designing the tooling, and producing the filament heaters. The cathode suppliers provided the design requirements, the required quantities and evaluation of the products. Functional testing was carried out at the cathode manufacturers in order to minimize potential for hidden problems. After evaluation, it was determined that the Nippon Tungsten material was acceptable to both Semicon Associates and Spectra-Mat.

5.2.3.2 Evaluation and Implementation of Eddy Current Inspection

Prior to this program, inspection of incoming material was limited to a manual and visual process for a small sampling of the entire spool of wire. Another important issue was the lack of baseline data to keep track of quality discrepancies.

Within their program plan, UCF was able to lease an eddy current tester and conduct equipment specification, fixture development, and engineering validation of their technology. By using eddy current testing, UCF will be able to test 100% of all its filament heaters. This will enhance reproducibility, reduce the risk of missing material flaws and defects, and reduce overall process cycle time.

In order to establish a metric of their success and to better understand their manufacturing operation, UCF expended an extensive effort in collecting baseline data before the eddy current system, and then afterward. Baseline data was obtained on wire splits during fabrication as well as coating integrity. This baseline data was collected and compared with the current method to ensure that new method performed as expected.

UCF began collecting baseline data on 4 May 2001. They have been recording lot size and defective quantity for all uncoated heaters made from 3% Rhenium-Tungsten, which had visible slits in the wire. The inspection was performed at a magnification of 40 times (X). A total of 22,772 heaters were inspected. Of these, 562 pieces were found to be defective or 2.47%. UCF began recording the lot size and accepted quantity for all coated heaters without any flaws visible at a magnification of 10 times (X). Of the 15,137 heaters that were inspected, 1,787 pieces or 11.8% were found to defective with coating flaws.

IITRI provided technical support for independence evaluation, documentation, and training. Specifically, IITRI provided technical support in the development of test methods for acceptance testing and identification of appropriate spooling equipment and fixturing required to implement new eddy current testing. By leasing the proper equipment and obtaining the training UCF was able to inspect incoming material 100%

and compare it with baseline data. Results show (see table below) that once eddy current equipment was in place and operational at UCF, they were able to reduce scrap by 57%.

SUMMARY TABLE ON SPLITS		
Number of parts: 21029	Splits before Eddy Current: 503	% Rejection: 2.39
Number of parts: 6657	Splits after Eddy Current: 92	% Rejection: 1.38
Improvement using Eddy Current: 57.78 %		

Other direct benefits for UCF from having the eddy current equipment include: ease in which a supplier of incoming material will accept rejected material based on data collected from eddy current testing; it provides a potentially alternate source of income by using equipment to perform eddy current testing for companies that outsource that service; and it gives UCF the potential to cut costs and produce a higher quality product.

5.2.3.3 Process Mapping and Simulation Modeling

With the help of IITRI, UCF also began laying the groundwork for process simulation modeling. After the baseline data was obtained, it was placed into a computer model that was built to simulate scrap rate prior to eddy current and post eddy current. Results agreed well with the data that was obtained. Process simulation modeling will allow UCF to make process decisions prior to implementing any actual changes and determine the outcomes of the changes at a minimal cost. If bottlenecks arise in current processing, the software allows them to investigate and resolve any issues. Planning for the future in terms of adding new equipment also becomes more feasible. With relatively inexpensive software, UCF now has capabilities to advance itself into the next generation of process flow and be able to respond to any demands that may appear in the future.

To summarize, by qualifying alternate sources UCF eliminated the dependence on one supplier of the Tungsten-Rhenium wire. Additionally, the new testing method has simplified the inspection method and improved reproducibility of the test results. Baseline data has been established and through comparison of methods shows a reduction in scrap with new process. Modeling capabilities increase the capabilities of UCF to meet future demands. The overall successful outcome of these projects has increased product availability, provided consistent quality, and reduced lead-times.

5.2.4 H. Cross Company - Manufacturing Process Improvements

H. Cross Company is the sole domestic supplier of Tungsten filament tape used to make the helix component of MPTs. The company is located in Weehawken, New Jersey, employs about 50 people, and does approximately \$5 million per year in sales. The MPT

industry is a very small percentage of their sales, but they make a component that is critical to all helix traveling wave MPTs. The primary manufacturing goals for H. Cross were the following:

- Qualify alternate raw material suppliers,
- Evaluate new eddy current test equipment, and
- Decrease process throughput time of materials.

These goals were selected so as to increase H. Cross Company presence in the global marketplace and to ensure future company viability and helix tape supply. Finally one of the manufacturing process improvements was to institute supplier certification program and cross training of employees to increase competitiveness.

H. Cross first established a baseline of their current typical processes. The particular factors baselined were lead-time, percentage of “on time” deliveries, and rejection rate. Next they worked closely with the three primes (BEDD, CPI, Northrop) to establish testing procedures to qualify the new helix tape. The primes obtained baseline data from the legacy material so as to be able to compare with the new incoming material. H. Cross Purchased and reviewed materials from Allied Material Corp. and Nippon Corp. The Allied Material review included three Tungsten types. The Nippon review included one sample of pure Tungsten and one sample of 3% Tungsten Rhenium.

Materials were to be evaluated for surface finish, split levels, formability, and workability versus Osram materials. For Allied Material the overall quality is better than current supplier, based on samples that were examined. New material can be produced using existing processes without problems. There was no noticeable difference between AX and EX grade regarding production. Furthermore, lead-time for the new material is approximately 6-8 weeks after receipt of order (A.R.O.). It is also slightly cheaper than current supplier overall (Including shipping charges). The Nippon analysis for pure Tungsten had an overall better quality than current supplier. It can be produced using existing processes. Current lead-time for this material is 6-8 weeks (A.R.O.). It too is slightly cheaper than current supplier. The 3% Tungsten Rhenium also has an overall better quality than current supplier. As the pure Tungsten it can be produced using existing processes. The lead-time for this material is about 8-10 weeks (A.R.O.). Finally this material is slightly more expensive than current supplier, but may be worth the added expense in terms of having a better quality.

As one of the goals from this program was to improve its equipment H. Cross decided to evaluate its current eddy current testing equipment and compare to new system it would acquire. H. Cross had an older eddy current tester and thus evaluation of the new eddy current system was done to compare their capabilities. The new equipment uses faster processors and has higher frequency ranges than the older equipment. The new unit also has multiple filtering versus single filtering on the older unit. In order to compare the equipment H. Cross tested materials at same settings as older unit for baseline comparisons. The tests performed used four different materials requiring different diameter test coils. Both pure and Tungsten Rhenium materials were sampled. The test

pieces had known features so as to facilitate the comparisons. Initially these results compared very well, while the application of secondary filtering increased discrimination of splits versus older equipment. Once these results were obtained H. Cross began testing the same material at the higher frequencies afforded by new style equipment. Test charts showed an increase in background noise due the lower depth of penetration at higher frequency. The split-levels increased in amplitude due to higher concentration of eddy currents at surface. These increments were consistent between pure and Rhenium Tungsten samples. The last stage was to increase testing time once the new equipment was put into place and calibrated. The goal of increasing testing speed was achieved at 45 Fpm for tape and 90 Fpm for the wires. This increase in speed will allow for testing of three times as much material as previously allowed. The tape capability increased from 900 feet to 2700 feet per hour. The wire capability increased from 1800 feet per hour to 5400 feet per hour.

One of the ideas for improvement was to institute a supplier certification program at H Cross Company. This would further increase their viability in the future. American Management Associates gave the training course. The course provided basic framework and metrics by which suppliers can be quantifiably measured and graded. In order to try and position themselves as a strategic ally with major suppliers H. Cross is instituting the program. Data is being logged for the future rating system and supplier scorecard. It is their hope to reduce their supplier base to four or five top suppliers for all raw materials. They will also explore possibility of securing more favorable raw material prices through use of Kanban agreements and multi year purchasing agreements.

In order to improve production and to maintain quality this program provided H. Cross support to implement a cross training program within their plant to increase manufacturing flexibility by cross training employees. Many of their departments have two or less operators. These operators will be rotated on a scheduled basis within various departments as workload and scheduling allow. Scheduled meetings will take place with employees to review status and possible changes to the program. Additionally a secondary program will be instituted to form cross-functional teams within workplace.

To date about 25% of machine operators were given initial exposure to different jobs in areas including slitting, roll grinding, hand rolling and annealing. Currently 20% of operators are proficient enough to assume other duties as time dictates. This improvement allows for work to continue in cases of vacation or worker illness in all departments.

The participation in this project has enabled H. Cross to evaluate two other potential suppliers of raw materials with input from the prime contractors. It has allowed H. Cross to improve testing capabilities and product throughput without increasing manpower or equipment. It enabled them to train key personnel in the area of supplier management and certification. They have been able to increase their presence and positioning for products in the global marketplace insuring future viability and the future supply of helix tape. Finally DPA Title III permitted them to cross train current employees making them more flexible in production and ultimately a more reliable company.

6.0 STRATEGIC IMPLICATIONS FOR DOD – ACCOMPLISHMENTS, RECOMMENDATIONS, AND CONCLUSIONS

DoD has long been concerned about the viability of the microwave power tube industrial base. The issue was raised in 1972 and throughout the subsequent years. Beginning in 1990, this concern became accelerated and there were several studies conducted. These included a report in March 1990 entitled, *Critical Technologies Plan*, and the DoD Advisory Group on Electron Devices reports entitled, *Microwave Tubes: A National Security Concern* in July 1990; and *Microwave Tubes: Meeting the DoD Requirement*, in September 1993.

Since that time, DoD has taken various approaches to resolving this dilemma, including appointing a DoD Executive Agent in May 1997. This position is staffed by the U.S. Navy, the largest DoD user of microwave power tubes, and is currently held by Rear Admiral Michael G. Mathis. These initiatives, however, have primarily focused on assisting the MPT producers and internal DoD efforts.

A previous MTIAC study conducted for DoD indicated that one major weakness in the industry is the reliance of MPT manufacturers on a very limited number of subtier suppliers for several components and materials. At least 20 components or materials were identified as having only one or two suppliers globally. Furthermore, many of these suppliers were small businesses, reliant on the MPT industry and with limited resources for diversification or investments.

This program, initiated by the Office of the Deputy Under Secretary of Defense, Defense Production Act Title III, addressed the here-to-fore neglected issue of the subtier, small business supplier base.

The mission of the Defense Production Act, Title III (Procurement) is to create assured, affordable, and commercially viable production capabilities and capacities for items essential for national defense. This mission is achieved by establishing partnerships and providing incentives to industry to create, expand, or preserve economically viable production capabilities. The goals of this program are as follows:

- Facilitate technology transition and insertion,
- Establish affordable production capacity to support DoD requirements and pursue commercial markets,
- Maximize use of commercial production capabilities,
- Drive cost reductions,
- Induce quality improvements, and
- Enhance technical competitiveness of domestic firms.

In recent times, the majority of Title III Defense Production Act programs have dealt with creating a market and business base for a leading edge technology that was developed as DoD specific or where there is limited capacity for a critical material or component, such as Gallium-Arsenide/Indium Phosphide, metal matrix composites, and silicon carbide.

The distinguishing aspects and challenges of this project are as follows.

- The technology and products are mature, and market demand is in decline.
- Each of the four subtier suppliers (H. Cross Company, Semicon Associates, Union City Filament, Spectra-Mat, Inc.) is an established, small business currently operating in declining markets.
- The four subtier suppliers do not sell directly to the Government, they are not organized to do so, and they had limited experience in conducting R&D under a formal contractual structure.
- Many of the participants, which includes the microwave power tube producers and the subtier suppliers, are competitors, creating complexity in the sharing of information.

6.1 Accomplishments

Each of the four companies has addressed both business and technical issues including: development of a strategic business plan, marketing plan, manufacturing improvements, and has conducted a demonstration/briefing of the achievements of their specific program. The accomplishments of this program can be summarized in the following five areas:

- Material management
- Process control and documentation
- Flexible and knowledgeable workforce
- Diversification of product and/or customer
- Component acceptance criteria

Material Management

Acquisition of quality starting material in a reasonable time and cost was a major issue for both H. Cross Company and Union City Filament. Both companies have qualified an alternate supplier of Tungsten and Tungsten Rhenium wire. By doing so, they have eliminated their prior sole source dependency on starting material for helices and filaments used in the manufacture of DoD microwave power tubes.

Another issue related to material management is incoming inspection. This was also identified as a major cost and lead-time driver for both of these companies. The technology of choice is eddy current testing. In conducting this program, H. Cross Company has upgraded their eddy current capability and has increased the speed of inspection for incoming wire three-fold. Prior to this program, Union City Filament had no eddy current capability and can now perform 100% inspection of incoming material.

The overall benefit to DoD is improved lead-time, readily available sources for material, and reduced inventory requirements that will contribute to the profitability and viability of these subtier suppliers.

Process Control and Documentation

In any manufacturing operation, process control is a major factor in business success. Typically, the better a manufacturing entity can control their process, the lower their material loss, there is less interruption of scheduling and work flow, and less cost associated with non-value added activities. Related to process control, is process documentation, which promotes consistency in product quality, and the ability to produce parts that are infrequent orders and small lot sizes. This is particularly important to supporting the spare parts requirements for DoD weapon systems.

Through improved process knowledge gained in conducting this program, Union City Filament has reduced scrap and rejection rate by 57%. In addition, IITRI and Union City have documented their process flow using off-the-shelf software and have also created computer simulation models of processes within their organization that will enable future process improvements.

In the area of process control, Spectra-Mat has focused their effort on improving surface related technologies, particularly coating technology. Improved resource planning is an ongoing and major endeavor for both Spectra-Mat Inc. and Semicon Associates.

Process documentation is being addressed by all of the subtiers, but especially by Semicon Associates. Their accomplishments in this area include generating databases of over 900 method sheets, over 500 pages of processing documentation, and over 900 digital photographs illustrating acceptance criteria. Further, Semicon has implemented process documentation and method sheet development as an ongoing business practice and in the future will no longer be dependant on the "art of the worker". Semicon estimates that these quality improvements will yield \$80,000 annually in tangible savings.

The benefit to DoD is that these process improvements will facilitate the following:

- Opportunities to expand their business through providing higher value-added processes,
- Anticipate lower costs due to simplification of some processes, and
- Allow greater repeatability of processes.

Flexible and Knowledgeable Work Force

H. Cross Company used this program as an opportunity to implement a company-wide cross-training program. In addition, three of their key personnel attended a supplier

management training course and they are in the process of assessing their own vendors and developing a formal approach to supplier management.

Semicon Associates is also addressing this area from a slightly different perspective, they are training internal people to do training. On average, Semicon has reduced their employee training time by 30%. Union City Filament has participated in eddy current analysis training and in the use of computer modeling tools.

The benefit to DoD is that these suppliers are better able to meet schedules, are stronger in their the ability to withstand production and market downturns, as well as being better positioned and more flexible in accommodating surges in production demand.

Diversification of Product and Expansion Of Customer Base

The cost of marketing, especially to offshore businesses, has been a major impediment to business expansion for each of the subtier suppliers. It was recognized that a website would be a low cost mechanism for reaching not only a broader market base, but their current customers as well. This program provided an opportunity for H. Cross to develop a website, for Union City to initiate this activity, and for Semicon Associates to develop a site dedicated to their business segment, rather than being limited to a mention within their corporate owners site. Already, H. Cross and Semicon have received additional orders and numerous inquiries from potential new customers. Semicon also used this program as an opportunity to develop new promotional materials and to expand their market awareness through activities such as the capability demonstration.

Spectra-Mat began diversification in the early 1990s when the MPT industry began its dramatic decline. In particular, Spectra-Mat has expanded their cathode product line, and has excelled at specialty applications and small lot sizes. Further expansion into new markets, such as specialty materials would add to Spectra-Mat's technical capabilities, assist them in supporting future MPT designs, and contribute to their ability to support DoD's long-term cathode requirements.

Semicon is also seeking to expand into other product segments that would utilize their equipment and capabilities. Semicon, at the encouragement of their key customers, is working toward enhancing their ability to do cathode gun assemblies. This is a higher value-added process that would allow them to grow, while still meeting the needs of the MPT industry and DoD that they currently fill.

The benefit to DoD is financial stability for companies through a larger business base in supporting a declining MTP market, and greater resources to update equipment and requirements for future systems.

Component Acceptance Criteria

Ambiguity as to what is an acceptable cathode or filament has always been a major point of contention between the MPT producers and the cathode and heater filament makers. A major achievement of this program was the development of two engineering specifications that define processing and final acceptance criteria for dispenser cathodes and cathode heaters (filaments). Prior to this effort, the industry had no engineering specifications that sufficiently defined the performance requirements for their products. MTIAC provided the framework, funding, and technical coordination for these two product specifications.

These specifications will be utilized by the MPT industry and respective suppliers. The documents are being disseminated throughout the industry. It is anticipated that the Electronics Industry Alliance will take ownership of these documents and that the Naval Surface Weapons Center, Crane will maintain them. The benefit to DoD is that the MPT producers and suppliers will be able to meet schedule and, in the long-term, there is the potential for higher reliability, lower cost, and should the need arise, greater flexibility in developing alternate suppliers

6.1 Recommendations

As a result of the experiences and lessons learned in conducting this program, the following recommendations are made for future efforts to further strengthen and preserve the industry.

- **Create a computer simulation model of the cathode manufacturing process.** In developing the process audit criteria and specifications, Semicon Associates and Spectra-Mat, Inc. participated in process mapping the cathode manufacturing process. This data could readily be used as input to a computer simulation model. Process modeling not only documents the current methodology, but helps identify opportunities for greater process efficiency and “what-if” analysis.
- **For future projects, solicit greater participation of other suppliers, especially** Teledyne Electronic Technologies and Triton Electron Technology Division. If rare earth magnets are included, Electron Energy Corporation (EEC) should be invited to join the project team as well. Teledyne and Triton were invited to meetings and receive all major presentations.
- **Analyze, characterize, and improve cathode coating materials.** Cathode heater filaments are produced by Union City Filament (UCF) but they are also manufactured by both independent and captive cathode manufacturers. In practice, cathode producers frequently make their own prototype requirements and outsource orders of any significant quantity. UCF is acknowledged by the customer base for quality production at affordable prices. UCF has made significant improvements.

What is unique to UCF are their coatings. They are the sole producer of the heater filament coatings that are used by all of the cathode producers. UCF developed these essentially by trial and error. Project opportunities would include characterization and optimization of these formulas. It is recommended that UCF not only characterize the properties of their current coatings, but also to use that information to develop an improved coating, as well as assessing methods for improved processing and coating application. A better understanding of adherence of coating to the wire surface will allow improvements to be made on the coatings currently used. There are improvements to be addressed made in terms of geometry of particle and particle size. Certain geometries and sizes of particles can lend to adhere easier on the surface and so as study can be conducted to understand these relationships better and how to optimize them to create an improved coating.

A key benefit to DoD is the opportunity to preserve the technology and potentially improve part performance.

- **Assist Union City Filament in upgrading their heat treatment capability.** Union City has already achieved a better than 50 percent reduction in scrap through participation in this program. The next major cost and quality drive is their furnacing capability. Upgrading and characterizing their heat treatment processes will lead to further reduction of scrap, better lead-time if parts are right every time, and ultimately, lower cost.
- **Continue to work with cathode producers in expanding their business base.** The opportunity for subtier supplier growth in the MPT industry is primarily in offering additional products or services. To further explain, the MPT industry anticipates modest growth over the next few years, but the sales value of cathodes, filaments, or helices will most likely remain stable. To illustrate, in 1987 MPT sales were \$542 million and by 1992, these had dropped to \$275 million. In 2001, U.S. sales of MPTs (including cross-field amplifiers and Klystrons) are estimated at \$249 million. On average, cathodes represent about 5% of the cost of a tube. Even if the industry grows 10% per year, this would represent about only \$1.2 million in annual growth for cathodes, divided among the MPT producers themselves and the subtier suppliers. Real growth, and continued business viability for cathode producers, lies in either offering additional services or diversification.
- **Continue to support the development and maintenance of industry specifications** and to strive for further standardization of processing requirements throughout the industry. The documents produced under this program represent an initial effort for this industry, but there are other areas where specifications would benefit DoD and the MPT Industry, particularly metallization and plating of Beryllium Oxide ceramics.
- **Continue the work initiated in this task toward process documentation and expand to support e-business and, eventually, virtual manufacturing.** There is a strong opportunity for the MPT industry to lower transaction costs and enhance

information flow, particularly related to cathode production. What is envisioned is an e-business system to directly download information on cathodes, such as label data, from the supplier to the MPT manufacturers. Another opportunity would be a shared statistical process control (SPC) database between the MPT producers and suppliers such as Semicon Associates, Spectra-Mat, Inc., or other similar suppliers not necessarily addressed in this program. This type of data collection would also allow MPT producers, DoD, and suppliers to conduct trend analysis and better process control and the ability to predict their requirements.

- **DoD and the MPT industry should continue to track and address the issue of helix tape and wire.** The H. Cross Company is currently the only supplier of helix wire and tape and through participation in this program; they have made tremendous improvements, both technical and operational. The MPT producers themselves have tried to make helix tape, but claim that it lacks the quality of the H. Cross product. H. Cross is a family-owned business that has always supported the MPT industry and states that they are committed to continuing to do so. They have remained the sole supplier through technical know-how, proprietary equipment, and strategic pricing. They are working to expand their business base as a supplier of tight tolerance refractory and other materials and fabricator of specialty metals. However, external economic factors could impact their viability, especially in key markets such as lighting.
- **Document the extent to which Tungsten Rhenium is used in MPT production** and assess the vulnerability if this was no longer available. The primary use of Tungsten Rhenium is for Cathode Ray Tube (CRT) screens. As flat panel displays replace these, the market incentive will go away and the major sources of Tungsten Rhenium, Nippon Steel and Osram Sylvania may choose to quit making it. CPI uses Tungsten only for internal efforts. However, many MPT designs are utilizing Tungsten rather than Tungsten Rhenium. However, the impact of this material not being available should be investigated.
- **Investigate DoD internal manufacturing capabilities at depots, arsenals, and related facilities** as an alternative or second source for critical components in cases of emergency.
- **Continue to promote technology transfer and widespread information dissemination.** This is particularly important for not only exchanging information within the industry, but also in bringing new concepts and information from other industries to the design and manufacture of MPTs. Technology displacement rarely comes from within the industry it displaces. In his speech at the 2001 Defense Manufacturing Conference, Dr. Chester Lob, former Vice-President of CPI and ex-President of the Microwave Tube Division of the Electronics Industry Association, attributed the tremendous advancements of the tube industry to the development and advancement of new materials. Dissemination of the needs and advancements within and beyond the MPT industrial base will encourage the technical advancements needed.

To ensure that the information and knowledge obtained in conducting this program is disseminated throughout the U.S. MPT supply base, MTIAC is using a variety of opportunities as described below. Copies of slides and proceedings of these presentations are available through MTIAC.

:

- A program kick-off meeting was held 9 May 2001 in Chicago, Illinois
- A general meeting was held 30 August 2001 in Arlington, Virginia
- A general briefing to industry was conducted 2 August 2002 in Lexington, Kentucky
- A presentation of the approach, progress, and benefits of this program was given at the 2001 Tri-Service Vacuum Electronics Workshop, held 28-30 August 2002 in Arlington, Virginia
- A presentation was made at the 2001 Defense Manufacturing Conference held November 2001 in Las Vegas, Nevada
- Published reports will be available, as appropriate, through MTIAC
- The engineering specification documents will be available through Naval Surface Warfare Center (NSWC) Crane/Electronic Components, assemblies, and materials Association (ECA)

Each of the four subtier suppliers conducted a Capability Demonstration:

- Spectra-Mat, Inc., held 28 June 2002
- Union City Filament, held 8 July 2002
- Semicon Associates, held 1 August 2002
- H. Cross Company, held 2 August 2002

In addition, to the previous recommendations, there are two areas identified that represent opportunities for technical Research, Development, Test, and Evaluation (RDT&E). These are potting and optical inspection. Potting is an industry-wide problem for cathode production. While current specifications address acceptable levels of cracks and defects, the opportunity exists to find materials or processes that would eliminate these flaws. The benefits to DoD would be lower processing and inspection costs, but to a larger extent, greater reliability and enhanced technical performance.

Inspection is a major cost driver in most labor-intensive manufacturing processes and certainly in cathode manufacturing. In conducting this program it was discovered that there is the potential to create an optical method to measure radius of curvature on a cathode button that would speed up the process time tremendously. Development of such a computerized system would also provide a higher degree of accuracy by eliminating subjectivity of operator assessment.

6.3 Conclusions

As a result of the investment made by the DPA Title III in this program, the supply base for cathodes, helix tape, and heater filaments has made tremendous advancements and is a stronger and viable business base for the manufacture of military microwave power tubes. The following summarizes the specific benefits accrued to DoD through this program.

- There is **reduced risk to DoD of production shortfalls** for MPTs due to the lack of a supply base for Tungsten and Tungsten-Rhenium material. This DPA Title III program has reduced inventory cost and stockpiling through qualification of alternate suppliers.
- There are fewer parts returned, lower cost of scrap, and a faster overall lead-time from each of the four businesses, which translates to **a more responsive supply base for DoD**, especially in the case of military “surge” requirements.
- Improved process documentation that will facilitate opportunities to add higher value-added processes, lower costs due to simplification of some processes, and greater repeatability of manufacturing processes. The benefit to DoD is **reduced risk of losing the manufacturing process knowledge** for these components in both the near and long term.
- Lower marketing costs and reaching broader markets to expand the customer base through development of websites, market strategies, and promotional materials will **enhance overall business viability and help ensure continued support to DoD**.
- **Adaptation of modern manufacturing engineering tools** including process mapping and operational simulation modeling, cross training, and “enabling” the worker will position this segment of the supply chain to meet not only the needs of DoD today, but in the future as well.

In 1996, MTIAC conducted a review of flexible manufacturing in the microwave power tube industry. The study was sponsored by the DoD ManTech Electronics. The following areas were recommended for improvement to ensure a long-term supply base.

- Planning
- Process Standardization
- Process Characterization and Process Development
- Continue and Expand Flexible Manufacturing Initiatives
- Strategic Materials
- Process Control and Documentation
- Customer-Supplier Relations

While all of these problems and opportunities have not been resolved, each of these areas has been addressed through this program and the state of the MPT subtier supply base has been advanced. Through this program, each of the four small businesses that participated

made tremendous advancements in their ability to remain viable suppliers of DoD, components.

Planning -- In the previous studies, it was noted that the MPT producers made little or no use of simulation modeling and computerized process planning tools for optimizing process flow and process planning. Furthermore, the utilization of these tools would also support e-commerce and virtual manufacturing opportunities. The use of these techniques by subtier suppliers was thought to be even less feasible. One of the key accomplishments of this program was the demonstration of computerized process mapping and the development of a simulation model by Union City Filament. By demonstrating the simplicity for utilizing this technique, it is expected that others within the MPT industry will adapt it as well.

Process Standardization -- MTIAC and the project team has directly addressed this issue through the development of the two engineering specifications.

Process Characterization and Process Development -- This need has been addressed through by each of the subtier suppliers through their manufacturing process improvements.

Continue and Expand Flexible Manufacturing Initiatives -- testing, inspection, and management of outside services were the specific opportunities previously identified and each of these has been addressed by both the MPT producers and the subtier suppliers.

Strategic Materials -- this program has specifically reduced this problem through qualification of alternative suppliers of Tungsten and Tungsten-Rhenium

Process Control and Documentation -- Each of the four subtier suppliers has successfully addressed the issue of process control and process documentation. Union City Filament has done so through the implementation of eddy current inspection and data collection to support their process mapping and simulation modeling activities. H. Cross Company increased their capability to inspect incoming material by a factor of three, and Spectra-Mat has documented their process flow through participation in the Engineering Specification documents. Semicon Associates has made the greatest gains in this area through development of 900 process method sheets, 500 pages of process documentation, and a database of over 900 digital photographs. Semicon Associates estimates tangible savings at \$80,000 per year.

Customer-Supplier Relations -- This is perhaps the area where this program has made the greatest impact, especially through the activities of the Working Groups, the three general meetings that served as a forum for exchange of ideas, and the capability demonstrations. There is a greater understanding of the needs and capabilities for both the microwave power tube producers and the suppliers and there is a heightened awareness of the role and importance of the subtier suppliers. Of particular note is the amount of manufacturing engineering support the subtiers provide at both the design/development phase of a microwave power tube as well as in the manufacturing of spares and

replacement of out-of-production parts. Another important factor to note is the relative stability of the workforce of the subtier supplier base. In recent years, there has been extensive consolidation and acquisitions among the major MPT producers. However, the manufacturing know-how of the subtier suppliers has continued and through the support of this DPA Title III program, will continue to do so.

Collectively, the work of this project team has resulted in business and manufacturing process improvements that have made these businesses stronger and have advanced the state of manufacturing in the MPT supply chain. As a result of the investment made by the DOD Defense Production Act Title III program, the military supply base for cathodes, helix tape, and heater filaments is a stronger and more viable business base.

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Acronyms :

ARO	After Receipt of Order
Boeing EDD	Boeing Electronic Dynamic Devices (EDD)
CPI	Communication and Power Industries
DoD	Department of Defense
DPA	Defense Production Act
DTIC	Defense Technical Information Center
ECA	Electronic Components, Assemblies, and Materials Association
EDTA	Ethylenediamine Tetra-Acetic Acid
ESCA	Electron Spectroscopy for Chemical Analysis
IITRI	IIT Research Institute
ISO	International Standards Organization
MPT	Microwave Power Tubes
MTIAC	Manufacturing Technology Information Analysis Center
NSWC	Naval Surface Warfare Center
OEM	Original Equipment Manufacturers
SEM	Scanning Electron Microscope
SMI	Spectra-Mat, Inc.
TWT	Traveling Wave Tube
UCF	Union City Filament
VED	Vacuum Electron Device
WPAFB	Wright Patterson Air Force Base

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